A CASE STUDY ON SOUND LEVEL MONITORING AND MANAGEMENT AT LARGE-SCALE MUSIC FESTIVALS

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1 INTRODUCTION

Outdoor music festivals have become more prevalent over the past quarter century and are increasingly located in or around densely-populated areas. This trend has the accompanying effect of a (temporary) increase in noise pollution to the areas surrounding such festivals. Excessive noise pollution inevitably leads to noise complaints, which can in turn put the future of a festival at a given site in jeopardy. As the noise is temporary in nature, local residents' health isn't at risk, rather the local outdoor music event has the potential to cause annoyance in the community, resulting in formal complaints. In addition to annoyance due to noise pollution, the issue of dangerous levels of audio sound exposure has yet to be adequately addressed. It is likely to be the case that portions of the audience (and staff) are being put at risk when attending such events.

Significant efforts have been made in recent years, primarily in Europe, to adopt a proactive approach to sound level monitoring and management at large-scale outdoor music festivals. This generally includes monitoring sound levels at front-of-house (FOH) while simultaneously measuring noise pollution in the surrounding community. The aim of these efforts is to minimize noise-based annoyance for local residents through effective management of sound levels – including clear communication to those individuals affected (before and during an event). Events using sound level monitoring to protect the audience in addition to the local community are becoming more regular, but are still extremely few and far between outside of Europe due to lack of relevant regulations.

This paper details a case study focused on inspecting the effects of using sound level monitoring software at a large outdoor music festival, primarily looking into mix practices of the sound engineers and how this relates to audience sound exposure and listening experience. In the described experiment, sound level monitoring software was visible to the sound engineers on one of the two main stages at the festival. The observed effects of using sound level monitoring software are highlighted here with comparisons made to previous studies. Additionally, audience levels were tracked throughout the event to provide insight into the question of whether audience and staff are being put at serious risk of hearing damage due to such events.

2 BACKGROUND

Sound level monitoring at live music events has been the focus of a number of research projects in recent years[1-11]. These studies generally include on-site measurements throughout the course of an event at the mix location (front-of house, FOH) and in some cases also from audience members who have chosen to participate by wearing noise dosimeters. The bulk of these studies are concerned with temporary noise-induced hearing loss, but some look into the specific measurable effects of using sound level monitoring software at such events[1,2].

Most notably, a long-term study based in Australia investigated the effect of using sound level monitoring software by a venue's sound engineer[2]. In half of the monitored events, the sound engineer was allowed to see the sound monitoring software to see where the current mix level was in relation to the defined sound level limit. The other half of the monitored events didn't give the sound engineer sight of the monitoring software, but the software was still used to collect data.

The general trend in the data was that significant violation of the sound level limit was avoided with use of monitoring software, but mixes that may otherwise be quiet tended to increase in level, approaching the set limit. Without monitoring software, there were extremely loud acts, but also relatively quiet acts. In essence, the use of noise monitoring software by sound engineers seems to result in a decrease in the range of mix levels observed over numerous live events.

The resulting question, then, is an interesting one: which is worse, never having an extremely loud act, but having most acts cluster around the set sound level limit or having an occasional extremely loud act along with other quieter acts? This must be considered in terms of sound exposure of audience members and staff as well as annoyance of local residents. There is the possibility that the currently available monitoring software is doing more harm than good, even though it will keep the live events in line with local noise regulations. It should be noted that the data gathered in the Australian study was not found to give statistically significant conclusions. This points toward further work needed in this area[2].

There are a number of additional related studies which focus on aspects of sound/noise level management and monitoring at large-scale live events[1,3,4,7], quantification of annoyance levels due to different noise sources[12-17], health risks associated with sound exposure typically encountered at an entertainment event and aspects specifically related to low-frequency sound exposure (including infrasound)[7-11,18-33]. This published research is important in terms of the complete set of challenges encountered at live events, but will not be expanded upon in this paper. Further reading of the referenced material is recommended for those working/researching in this field.

3 EXPERIMENTAL DESIGN

The purpose of the experiment detailed in this paper was to investigate whether trends found in the Australian indoor music venue study[2] agree with what occurs at large-scale outdoor music festivals. The festival-based sound exposure and noise pollution studies detailed in Section 2[1,3,4,7] will serve as a comparison to data gathered here to help validate the results.

The experiment took place on the two main stages at Pitchfork Music Festival at Union Park in Chicago, Illinois, USA on 19 – 21 July 2019. Three of the authors from this paper (Hill, Kociper, Berrios) were directly involved with the design, deployment, optimization and operation of the sound systems for the two main stages (identified as the *Green Stage* and the *Red Stage*) through their work with Gand Concert Sound. This allowed the sound system design to be nearly identical on both stages, thus allowing for two comparable stages for the experiment.

Both stages' sound systems consisted of line arrays of 16 Nexo Geo-T 4805 loudspeakers plus 2 Nexo Geo-T 2815 down-fill loudspeakers per side (trim height and angles were identical for both stages). The only difference between the two systems was in the subwoofer arrays. The Green Stage's subwoofer array consisted of 20 Nexo CD-18 subwoofers while the Red Stage's array had 18 Nexo RS-18 subwoofers. All subwoofers were placed in stacks of two. The primary author of this paper designed the subwoofer arrays so that the coverage was as consistent as possible across the audience. The optimization parameters and modelled results are given in Tables 3.1 & 3.2 and Figures 3.1 & 3.2, respectively.

Stack	1	2	3	4	5	6	7	8	9	10
Pos. (m off center)	8.23	6.40	4.57	2.74	0.91	0.91	2.74	4.57	6.40	8.23
Delay (ms)	11.8	7.7	4.2	1.5	0	0	1.5	4.2	7.7	11.8
Gain (dB)	-3.0	-2.1	-1.4	-0.7	0	0	-0.7	-1.4	-2.1	-3.0

Table 3.1 Green Stage subwoofer array configuration parameters (10 stacks of 2 Nexo CD-18)

Stack	1	2	3	4	5	6	7	8	9
Pos. (m off center)	7.32	5.49	3.66	1.83	0	1.83	3.66	5.49	7.32
Delay (ms)	11.0	6.9	3.4	0.9	0	0.9	3.4	6.9	11.0
Gain (dB)	-3.0	-2.1	-1.4	-0.7	0	-0.7	-1.4	-2.1	-3.0

Table 3.2 Red Stage subwoofer array configuration parameters (9 stacks of 2 Nexo RS-18)

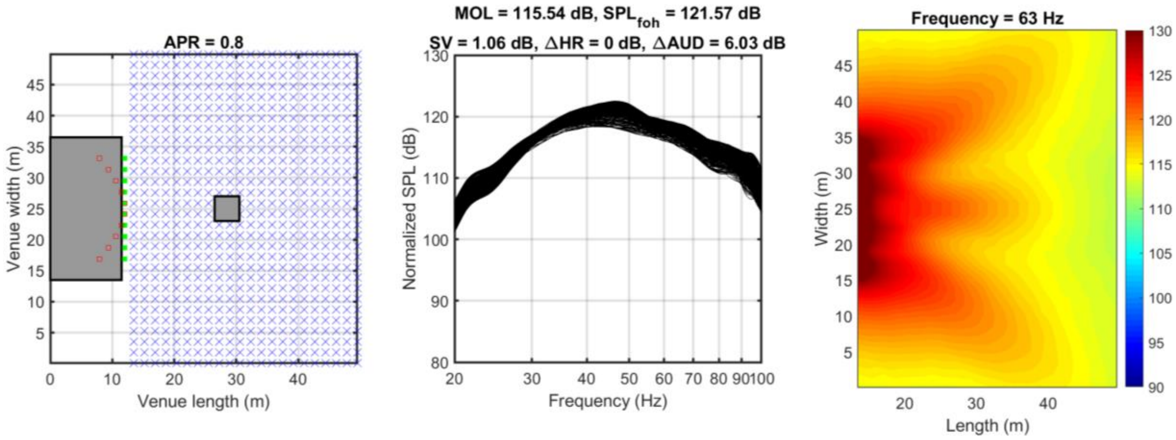


Figure 3.1 Modelled performance of the Green Stage subwoofer array (APR = array performance rating (0 – 1), MOL = mean output level, SPLFOH = mix position SPL, SV = magnitude response spatial variance across audience, ΔHR = change in system headroom due to configuration, ΔAUD = difference between average audience and mix position SPL)

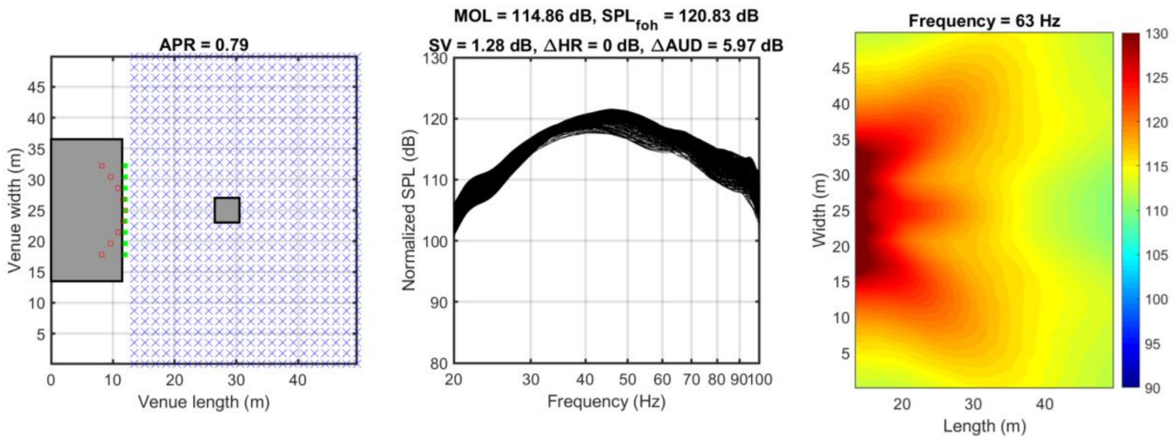


Figure 3.2 Modelled performance of the Red Stage subwoofer array (APR = array performance rating (0 – 1), MOL = mean output level, SPLFOH = mix position SPL, SV = magnitude response spatial variance across audience, ΔHR = change in system headroom due to configuration, ΔAUD = difference between average audience and mix position SPL)

The two subwoofer arrays were modelled using the primary authors' bespoke subwoofer array optimization software (not publicly available), which operates on the Array Performance Rating (APR) metric[34]. APR is on a scale of 0 – 1, with 0 representing extremely poor performance and 1 representing perfect performance. Both arrays had a predicted APR at the boundary of the A and B grade ranges. Sound pressure levels in the audience and at FOH were predicted to be within 1 dB between both stages, indicating consistent performance of the two arrays.

The experiment was configured as follows. Both stages were equipped with a laptop and a 10EaZy (Class 2) sound level monitoring system[35]. Each measurement system was located on the respective stage's FOH riser. The microphones were set to be at head height of the sound engineers, therefore approximately one meter above audience members' heads.

The choice of FOH as the measurement location is practical (as this is where the mix engineers work from) and in line with previous research at European festivals[9,47], where it was found that FOH levels accurately represent the overall audience exposure. Both measurement microphones were calibrated the day before the experiment began. The basis of the experiment was that while both stage's monitoring systems would log data throughout each day of the festival, only the system on the Red Stage would be made visible to the sound engineers.

Since the festival and city did not explicitly set sound level limits (on-site or off-site), it was determined by the authors that headliner and support act limits would be 100 dBA and 96 dBA, respectively, averaged over 5 minutes ($L_{Aeq,\ 5min}$). While many audience sound exposure and community noise pollution regulations stipulate a 15-minute integration window, a shorter 5-minute averaging was decided upon for a couple of reasons. First, as the set times for the support acts were 1 hour or less in length, a 15-minute average would make it difficult to effectively manage the sound level (i.e. if a support act's set began at a very high level, it may require the level for the remainder of the set to be significantly lower to ensure compliance with the limits). Setting the averaging to approximately the length of a single song was deemed more reasonable for this specific experiment. Second, based on one of the author's extensive noise monitoring/management experience, it was suggested that a shorter integration window aligns more closely to off-site noise annoyance (i.e. shorter instances of loud noises trigger annoyance, which isn't typically captured with a longer integration window). It is recommended to always align on-site and off-site integration times based on the shortest necessary time window (local regulations permitting). In this case, there were no level regulations, therefore the authors could define the sound level limits and integration times as appropriate.

While it is becoming increasingly accepted by researchers and practitioners that A-weighting is inappropriate for use in audience sound exposure monitoring (due to the limited significance of low-frequency content in the weighting curve), A-weighting was selected to align with current regulatory practice throughout the world. C- and Z-weighted sound levels were nonetheless recorded for analysis purposes.

The reason for monitoring sound levels using these additional weightings was in order to analyse the audience sound exposure throughout the course of the event. While monitoring sound levels at the mix position gives indication of specifically what the sound engineer is doing, this one position is not representative of every audience member's sound exposure. Audience members closest to the stage are likely to experience significantly higher sound exposure levels, potentially reaching dangerous levels even when the FOH levels are acceptable. This is particularly important to consider when using ground-based subwoofers, as was the case in this experiment.

In order to track audience levels, the sound system on the Red Stage was measured the evening before the festival opened. Measurements were performed using an NTI XL2 sound level meter. Pink noise was played through the system so that at FOH the sound level was 85 dBA (averaged over 10 seconds). Broadband and 1/3-octave spectral measurements were taken in 16 locations throughout the audience area. These measurements give relative levels in comparison to FOH, so that when FOH levels were monitored and logged, audience levels could be estimated.

Ideally, audience members would wear noise dosimeters (as was done in similar published research), but such devices were not available for this experiment. The relative level measurements, in any case, would give a good approximation of audience sound exposure. It should be noted that due to logistical (significant delays in erecting the stages) and meteorological (severe thunderstorms) issues encountered during the two load-in days of the festival, these measurements were taken very late in the day while quite a lot of work was still being conducted (including diesel forklifts). Due to this, measurements were only taken on the Red Stage, which was quieter (in terms of diesel forklift noise) than the Green Stage at the time. The assumption that both stages' sound systems operated similarly in terms of coverage pattern is relied upon to allow for complete analysis of the data.

A third data set that was tracked during the festival included audience, engineer and genre information. The audience distribution and density were tracked by the primary author (by eye) for each act by splitting the audience area for each stage into a 15-section grid, where density levels of empty, low, medium and full were used. These readings were taken two-thirds into each act's set, which was observed to generally be the point where audience size was at its peak.

Each act's music genre and type of engineer were recorded. There were two possible types of engineers: the band's engineer or the house engineer. The house engineers were two of the authors of this paper (Berrios on the Green Stage and Hill on the Red Stage). Recording this information would allow for a statistical analysis of the logged data to see which factors (if any) influenced the overall sound level throughout the festival.

4 RESULTS & ANALYSIS

The logged data from both main stages was analysed, according to the process laid out in Section 3.

4.1 System coverage

The relative measurements to FOH taken before the festival were analysed over the frequency range 31.5 – 100 Hz. The main PA (line arrays) was flown from the stage roof (the bottom loudspeaker was 5 m off the ground), spaced at 15 m. The subwoofer array, on the other hand, was ground-based and located 2 m from the first row of audience (with security personnel standing within 1 m of the array throughout the event). It is therefore of most interest to inspect the low-frequency sound level being delivered to the nearest audience/staff members to the subwoofer array. The measured sound pressure level (averaged over the 1/3-octave bands between 31.5 – 100 Hz) relative to the measurement at FOH is presented in Figure 4.1.

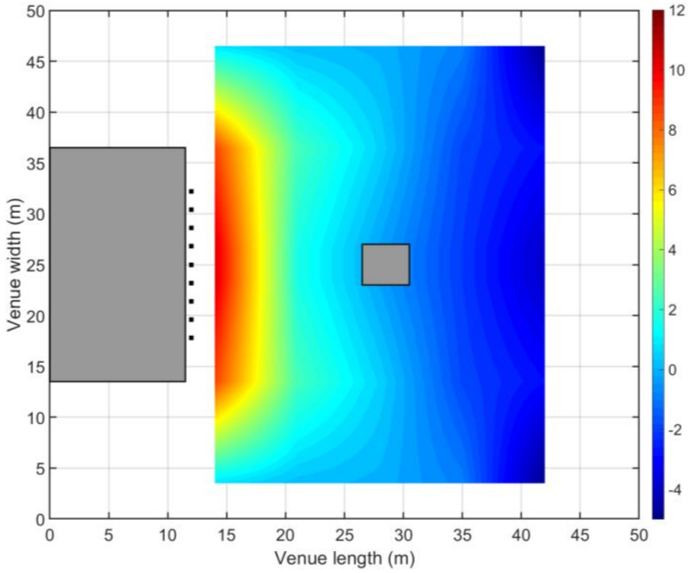


Figure 4.1 Mean sound pressure level (dBZ, relative to FOH measurement) from 31.5 – 100 Hz

The data indicates that at the front of the audience, the low-frequency sound pressure level will be approximately 12 dB higher than at FOH. At the rear of the audience, the level will be around 5 dB lower than at FOH. The measured 17 dB front-to-back difference in low-frequency sound pressure level is one of the growing number of reasons against using ground-based subwoofers at live events. Their use prevents consistent tonality and level across the audience. This has been explored in detail in recently published research[36].

The data shown in Figure 4.1 will be used to estimate low-frequency sound exposure levels to the front row of the audience in Section 4.3 of this paper.

4.2 Audience density and distribution

Information on audience density and distribution was recorded according to the procedure set out in Section 3. The audience data is presented for each act individually on Friday, Saturday and Sunday of the festival in Figures 4.2 and 4.3. Stage (Green or Red), set time, music genre and engineer type (band or house) is also indicated for each act in these figures.

Note that over the course of the festival, four acts' sets were either partially- or fully-cancelled. The two partial sets were less than half of the originally allocated set length and were under non-ideal conditions, therefore the partial set data was excluded and treated as fully-cancelled. This is indicated in all data analysed and presented in this paper.

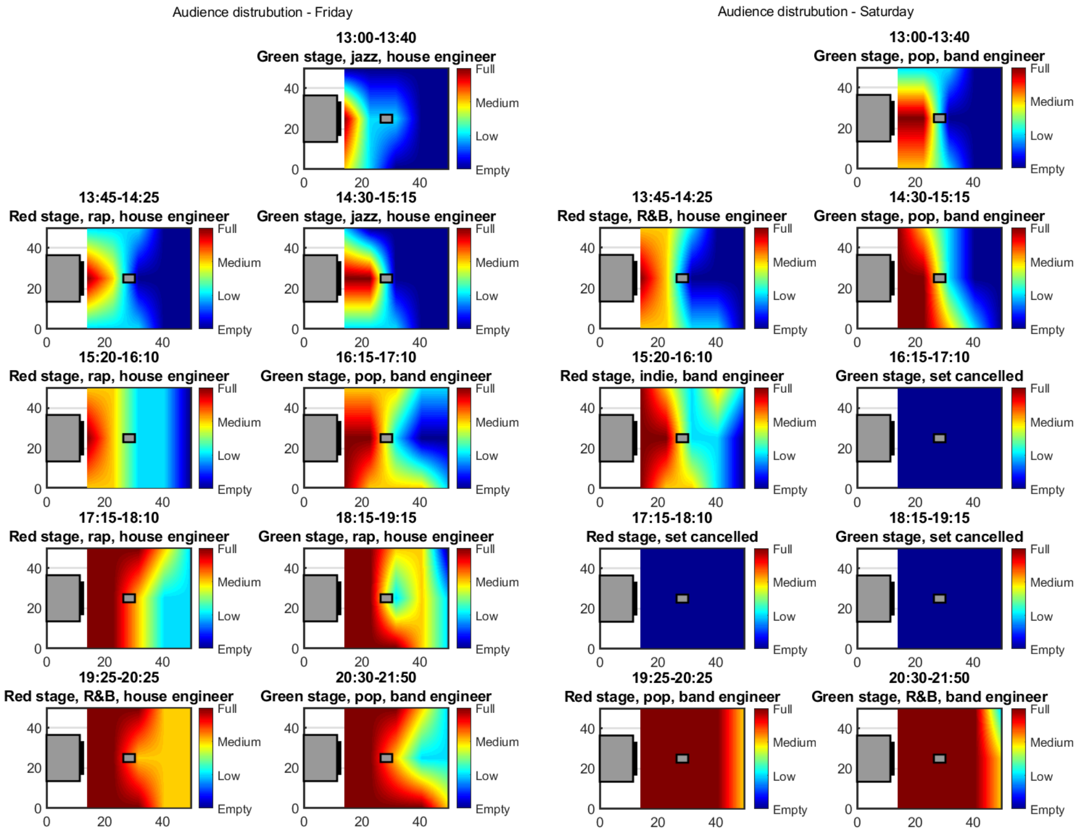


Figure 4.2 Audience distribution for Friday (left) and Saturday (right) of the festival

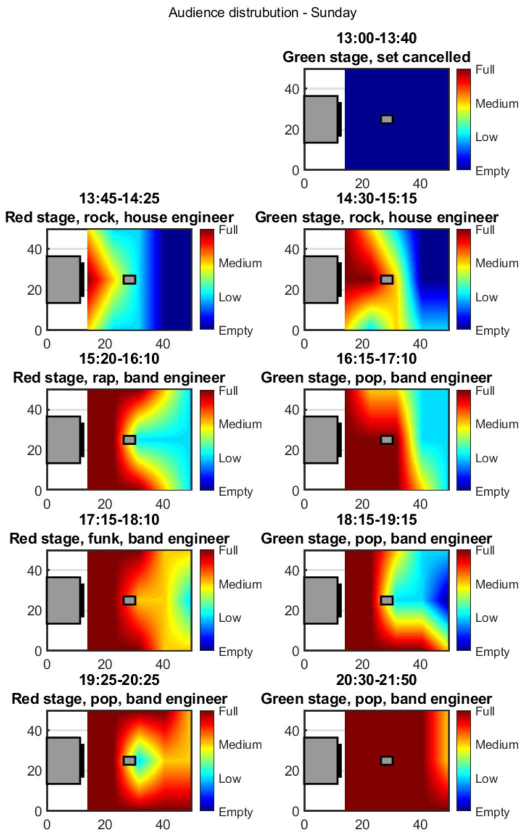


Figure 4.2 Audience distribution for Sunday of the festival

It should be noted that the festival weather wasn't ideal. On Friday and Saturday, the heat index was generally between 100 – 110 ºF (~38 – 43 ºC) during the daytime. A severe thunderstorm occurred during the middle of the day on Saturday, affecting three of the scheduled acts. This required the festival to be completely evacuated for approximately 90 minutes. The opening of the festival was delayed on Sunday due to another thunderstorm, causing the first act to be cancelled. The heat index on Sunday was closer to normal at around 85 ºF (30 ºC) during the day. Due to this poor weather, audience levels were lower (approximately 15,000) on Friday and Saturday as compared to Sunday (19,000 – the capacity of the festival site).

4.3 FOH sound levels

As detailed in Section 3, limits of 96 dBA and 100 dBA ($L_{Aeq,\ 5min}$) for the support acts and headliners, respectively, using a moving 5-minute average were chosen for this festival and logged throughout each day. On the Red Stage, the sound engineers had sight of the monitoring software which indicated where the current mix level was in relation to the limit. On the Green Stage, the data was logged, but the sound engineers had no sight of the monitoring software. In addition to the dBA limits, a secondary set of dBC limits ($L_{Ceq,\ 5min}$ of 106 dBC and 110 dBC for the support acts and headliners, respectively) was internally logged, but not visible to any sound engineer. This data was gathered in order to analyse sound levels with and without significant contributions from the low-frequency range.

The logged data is shown in Figure 4.3. Solid horizontal lines indicate the sound level limits. Items plotted in red or blue indicate A-weighted or C-weighted values, respectively. The grey lines correspond to audience density (right-hand y-axis). Solid grey lines indicate that the house engineer was mixing, while dashed grey lines indicate that a band's engineer was mixing. The background shading indicates whether the Green or Red Stage was active.

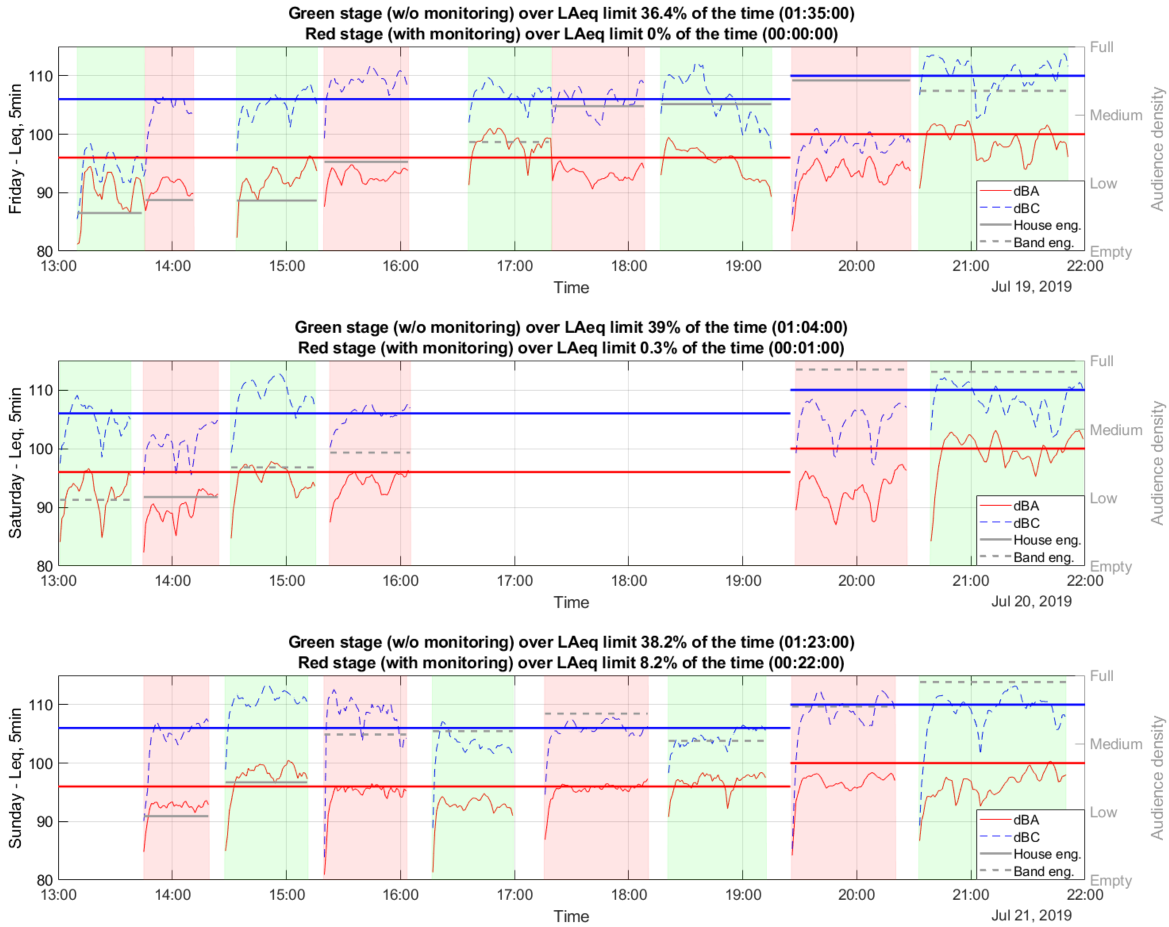
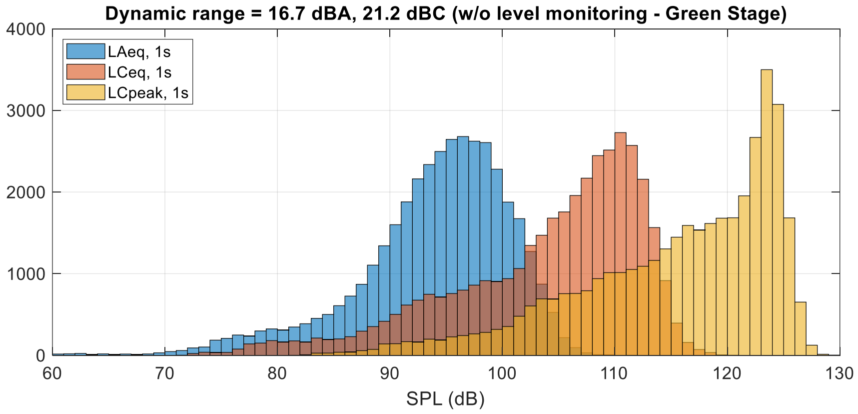


Figure 4.3 FOH sound pressure level data over the course of the festival

The primary data stemming from the information contained in Figure 4.3 is in relation to the amount of time the FOH sound level was over the limit. The Red Stage, where engineers could see the sound level monitoring software, was over the limit a grand total of 23 minutes during the festival (approximately 3% of the stage's "live" time). The Green Stage, on the other hand, where engineers couldn't see the level monitoring software, was over the limit a grand total of 4 hours, two minutes during the festival (approximately 38% of the stage's "live" time).

4.4 Dynamic range

In relation to the previous research of indoor music venues in Australia[2], there doesn't appear to be a similar trend of mix levels clustering around the set limit on the Red Stage. To further explore the data in this regard, both stages were analysed in terms of dynamic range (Figure 4.4). For completeness, A-weighted dynamic range histograms for each act are given in Figure 4.5. In this instance, dynamic range is something different to what it means in the recording and broadcast industries. Here, dynamic range is calculated based on the difference between the measured L10 and L90 values (the equivalent sound pressure levels exceeded 10% and 90% of the time, respectively). The integration time for this analysis was 1 second to better inspect the moment-to-moment mixing practice of the engineers in relation to the sound level limit.



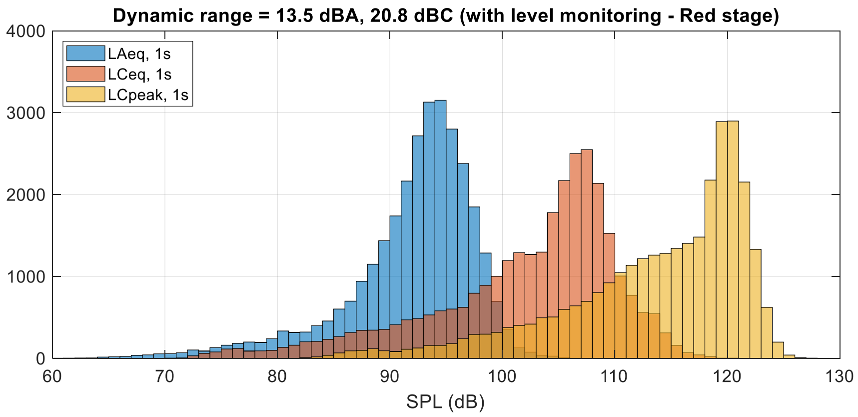


Figure 4.4 Calculated dynamic range for the Green Stage (top) and Red Stage (bottom)

This analysis reveals some interesting aspects of the data not immediately apparent in Figure 4.3. There is a clear reduction in dynamic range between the Green and Red Stages, where the Red Stage shows over 3 dB less dynamic range for A-weighted measurements (which was the weighting of the imposed limit). The C-weighted data, on the other hand, shows no significant reduction in dynamic range between stages. This gives some indication that the sound engineers who could see the sound level monitoring software (Red Stage) in effect compressed their mixes in order to comply with the limit. The low-frequency content, though, which isn't significantly represented in A-weighted data, was left largely unchanged.

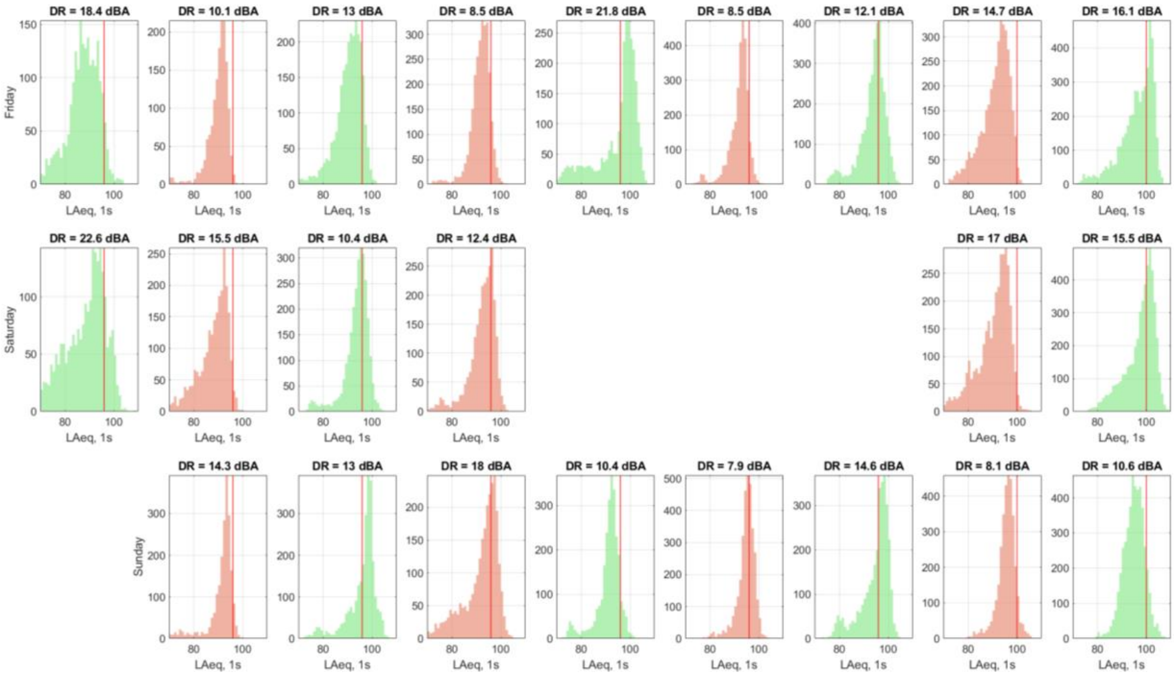


Figure 4.5 Calculated A-weighted dynamic range for each act (red lines = sound level limit) (note that empty spaces in the figure indicate cancelled sets)

Both sound systems were configured where the main PA (line arrays) was driven through the left/right mix bus on the mixing console. The subwoofers, though, were driven by a separate mono auxiliary send, which did not follow the level of the main left/right bus. This means that when engineers saw that they were running up to (and beyond) the set limits, they reduced the level of the main left/right fader, leaving the subwoofers untouched (as this low-frequency content has minimal impact on the A-weighted levels).

A notable trend in this data is dynamic range versus overall mix level on the Red Stage. The data reveals that dynamic range is inversely proportional to the overall mix level. Acts who had engineers that mixed right up to the limit all exhibit decreased dynamic ranges. The only outlier to this trend can be seen in the second Red Stage act on Sunday. This was a rap artist who spent a considerable amount of his set time talking to the crowd (with no music playing) as indicated by the long downward tail in the LAeq data. When this artist was playing music, his engineer utilized a number of compressors to maximize the sound level without breeching the limit.

Lastly, while not a central focus of this experiment (since it wasn't monitored), noise pollution is a significant issue with large outdoor music events in populated areas. While there is currently no consensus on how to precisely measure noise in the community to give an accurate prediction of annoyance experienced by residents, a commonly used metric is the difference between C- (or Z-) weighted and A-weighted measurements (Figure 4.6).

Research focused on this metric to quantify potential annoyance sets the threshold of annoyance somewhere between 15 – 25 dB, where most researchers favour 20 dB[40,41]. The data shows that few points throughout the festival pose a risk of community annoyance. The two points in which the 20 dB mark is exceeded were due to the act's introduction music. In both cases, the nature of the potentially offending sound was steady in nature (nearly a pure tone), so may not in reality cause annoyance, as it has been found that impulsive noises tend to be more annoying[40].

It should be noted that this metric is typically used for measurements off-site. The measurements used here are based at FOH, so it's highly likely that off-site the C- to A-weighted difference will be much greater due to high-frequency attenuation over distance, thus pointing to a potential noise pollution issue. The on-site C- to A-weighted difference could therefore be used as an indicator of needing to investigate potential off-site issues further.

It can be seen that there exists no significant difference in this metric between the two stages, indicating that the use of noise monitoring software with an A-weighted limit is unlikely to do anything significant to stem annoyance in the local community. This is at least partially due to the subwoofer system being controlled by a different fader on the mixing desk than the main PA. It was observed that engineers used the main left/right fader when adjusting mix level to comply with the limits, leaving the subwoofer fader untouched. An alternative weighting (such as C or Z) is likely to be more appropriate for sound level monitoring, but further research is required.

Figure 4.6 LCeq,5min – LAeq,5min data recorded during the festival

4.5 Audience exposure

Audience sound level exposure is an aspect of live events that has been discussed in general terms for 50 years (or more), but until relatively recently little has been done to critically assess the extent of the issue. The relative sound pressure level values obtained through the pre-festival measurements allow for an estimation of the audience sound level exposure throughout the festival, based on the data logged at FOH. The focus here is on low-frequency exposure, as audience members in the front rows of the audience were as close as 2 meters away from the subwoofer array (security and other event staff were sometimes located even closer).

For this study, the worst-case audience location was inspected, which was the central front row audience location. Inspecting the audience distribution plots in Figures 4.1 and 4.2, this area was full for every act of the festival, even though other areas were often sparsely populated. C-weighted peak levels (1 second average) were estimated from the front centre audience location based on the recorded FOH levels (Figure 4.7). A 5-minute moving average of the data is presented alongside the 1-second data which corresponds to the integration time used for the sound level limits.

The data reveals that the front-most rows of the audience were exposed to considerable low-frequency energy. The “live” time of the festival for each day was approximately 8 hours, corresponding to an average working day. During this time, the audience closest to the stage was exposed to low-frequency sound levels consistently between 120 – 130 dBC peak (5-minute average), peaking around 140 dBC each day.

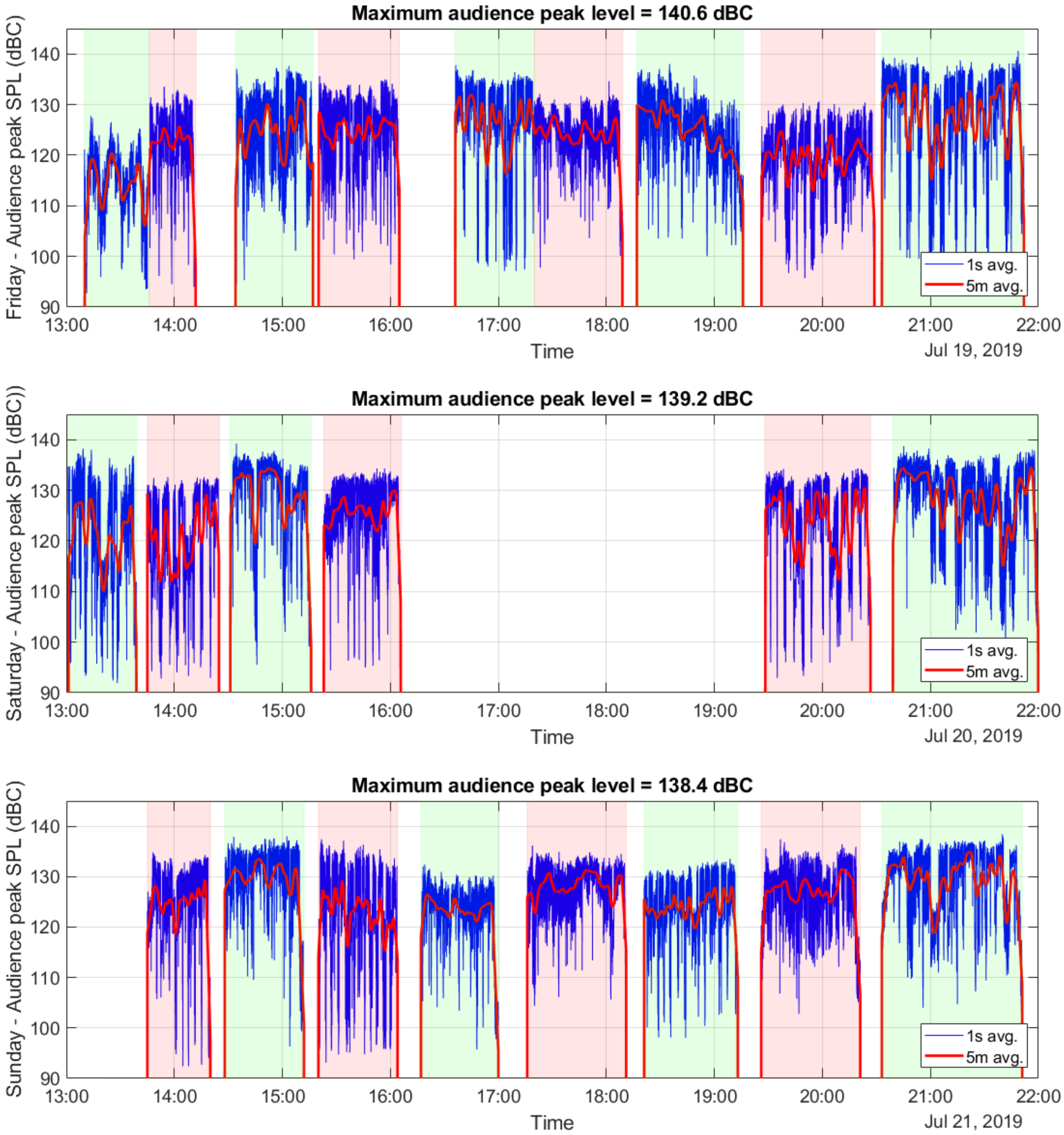


Figure 4.7 Estimated peak audience levels (dBC) during the festival

Many festivals make foam ear plugs available (free or at a cost) for attendees and staff in response to the acknowledgement that sound level exposure can lead to temporary or permanent hearing damage over time[5,6,42,43]. While such hearing protection is known to work well in the high-frequency range, it must be stressed that research has proven that such protection does little to mitigate low-frequency sound exposure risks[44-46]. This is due to the multiple pathways low-frequency sound energy reaches the inner ear. Even with the ear canals blocked, a significant portion of low-frequency energy transmits through the body through bone and tissue conduction.

The data shows that the audience was exposed to potentially dangerous levels of low-frequency sound and it is likely that they were unaware of the dangers, as it is widely assumed that foam ear plugs will protect ears from damage. Further work with industry is required to investigate whether the use of ground-based subwoofer systems should be discouraged.

4.6 Significant influences on FOH sound level

Lastly, it is important to determine the statistical significance (if any) of the data presented in this section. While the extensive study from Australia[2] raises a number of important questions about sound level monitoring for indoor music venues, the findings were not found to be statistically significant. A similar analysis is required in this study to see if any strong conclusions can be made.

To determine which variety of statistical test was appropriate, all sets of FOH sound pressure level data were tested to determine if they were normally distributed. Anderson-Darling tests were used for this purpose. In all cases, the data was found to be normally distributed, meaning that an analysis of variance (ANOVA) test would be appropriate. The null hypothesis for all tests detailed here was that there was no significant difference in the statistic under inspection due to the inspected variable(s).

4.6.1 Absolute FOH sound level

First, each act's mean FOH sound pressure level was inspected (in absolute terms, with no consideration given to the imposed limits). The data was inspected based on the following factors using a one-way ANOVA test: visibility of the sound level monitoring software, crowd size, engineer type (house or band), genre (jazz, rap, R&B, pop, rock) and time slot. These tests revealed that crowd size ($p = 0.0196$), engineer type ($p = 0.00883$) and time slot ($p = 0.0244$) were significant factors in absolute FOH sound level.

For low, medium and large crowd sizes, the FOH SPL ($L_{Aeq,\ 5min}$) averaged to 92.5 dBA, 95.0 dB and 96.1 dBA, respectively, indicating that engineers did (to an extent) adjust their mix levels based on the crowd size. House and band engineers had FOH mix levels ($L_{Aeq,\ 5min}$) of 92.7 dBA and 95.6 dBA, respectively. This shows that band engineers tend to mix louder than the house technicians. This finding should be dealt with using caution, though, as house engineers tended to mix earlier in the day when crowd size was smaller and the house engineer on the Red Stage was lead author of this paper and was fully-aware of the experiment taking place (hence would have been mixing with a bias, of sorts). While time slot did prove to be a significant factor, this finding should be treated with caution as the sample size was very small (between 2 – 3 data points per time slot). An extended study is needed to determine if this is truly an important factor.

A multi-way ANOVA was conducted on the data to determine any significant interactions between inspected factors. No significant interactions were identified.

4.6.2 Relative FOH sound level

The previous analysis ignores the imposed sound level limits; therefore, the test was repeated but on data that was relative to the level limits. These tests revealed that visibility of the sound level monitoring software ($p = 0.0358$) and time slot ($p = 0.045$) were significant factors. Multi-way ANOVA testing indicated that there were no significant inter-factor relationships.

On average, the mix level with and without view of noise monitoring software was 3.83 dBA and 1.61 dB below the limit, respectively. In other words, engineers who could see the level monitoring software mixed on average 2 dBA quieter ($L_{Aeq,\ 5min}$). This may not seem to be a huge difference, but in the world of community noise control this can make a significant difference. Again, time slot was identified as a significant factor, but the sample sizes were too small to consider this finding reliable.

4.6.3 Dynamic range (L10 – L90)

Finally, dynamic range (both A- and C-weighted) was inspected to identify any significant factors. In this instance, no one factor or combination of factors was shown to be significant. The closest factor to being significant was visibility of sound level monitoring software with a p-value of 0.09924. A long-term study (generating more data) is needed to draw stronger conclusions in this area.

5 CONCLUSIONS

This case study revealed a number of observations on the use of sound level monitoring software at an outdoor music festival. First, there was a statistically significant difference in mix level between using such monitoring software and not (approximately 2 dB lower mix levels). Use of such software prevented sound level limits from being breeched 97% of the time at the festival (as compared to roughly 60% compliance without monitoring). Mix level was shown to be proportional to crowd size and tends to be higher when a band's engineer is mixing (although the house engineers in this study were biased since they were conducting the experiment).

As it has been shown in previous studies[37-39], the dynamic range (or subjective impact) of live music is one of the primary aspects of the live experience that excites fans. If the use of sound level monitoring reduces dynamic range, it must be investigated whether or not this has a subjective impact. In other words, what is the just noticeable difference (JND) for dynamic range, as quantified in this manner?

Significant (and potentially dangerous) audience sound exposure was revealed. Audience members at the front of the audience were exposed to between 120 – 130 dBC peak regularly throughout the day, with daily peaks at 140 dBC. In such cases, the use of foam earplugs will not protect people from hearing damage (due to conductive transmission of sound), which points to the recommendation that ground-based subwoofer systems not be used. The use of A-weighted limits does not capture this issue, as evidenced by the independent nature of the A- and C-weighed data in Figure 4.3.

As this is a case study involving a single festival, the findings should be used with caution. Nevertheless, the results point to further work that is needed in this area to resolve certain ambiguities in order to generate a knowledge base that leads to the ability to simultaneously provide a safe festival experience for both audience and staff members while minimizing annoyance in the local community.

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